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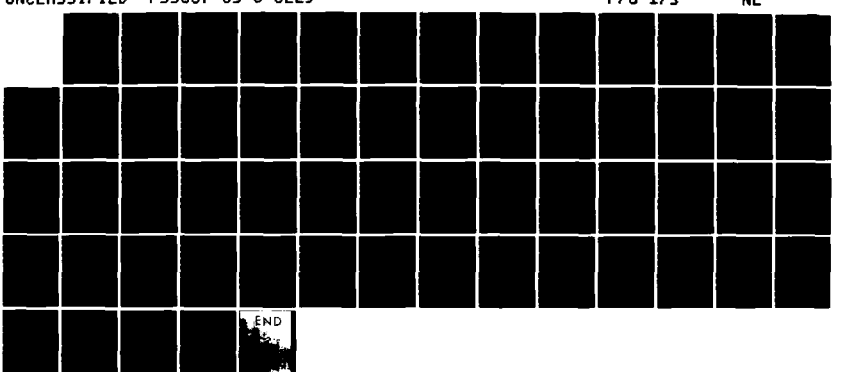

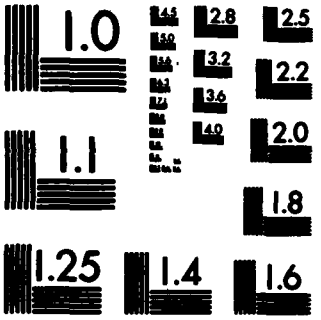

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AVIONICS INTEGRITY PROGRAM (AVIP) - VOLUME III

Program Cost Assessment - Environmental Stress Screening and Diagnostic Techniques

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MARCH 1984

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Final Report for Period September 1983 to March 1984

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AERONAUTICAL SYSTEMS DIVISION
AVIONICS INTEGRITY PROGRAM OFFICE
DIRECTORATE OF AVIONICS ENGINEERING
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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This report covers Gould Inc's ~~(NavCom Systems Division)~~ methodology of work with respect to Environmental Stress Screening (ESS) and represents an approach that can be demonstrated to result in increased integrity in the fielded product. It addresses the use of ESS as a concept whose effectiveness is achieved by exposing product to environments harsher than experienced in the field while not shortening its life. The pitfalls of the present procurement philosophy are exposed with major revisions recommended including that some of the funding that is currently in logistics support be spent as part of the initial contract budget to cause these failures to be removed. The total system savings to the Government by accepting a new method of work such as Environmental Stress Screening to reduce a logistics support budget are discussed. Additional topics discussed include: → (over)

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VOLUME III: COST IMPACT ANALYSIS WITH ESS SCREENING AND DIAGNOSTIC TECHNIQUES

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FOREWORD

This report is one of a series of four prepared for the Avionics Integrity Program Office, Wright-Patterson Air Force Base, Ohio. The reports address techniques and historical data (lessons learned) for enhancing the service life of avionic systems. The reports include contractor efforts between September 1983 and March 1984.

Each report represents a completed study in a specific area and stands alone. However, the contents of the four reports are meant to complement each other and they should be considered as the output of a single study aimed at determining those issues which contribute to the avionics integrity of military systems.

The titles of the remaining reports and their respective technical report numbers are provided as follows:

ASD-TR-84-5010, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Volume I, Procurement Phase Issues - Design, Manufacturing, and Integration

ASD-TR-84-5011, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Hardware Case Studies, Volume II

ASD-TR-84-5012, AVIONICS INTEGRITY PROGRAM (AVIP) STUDIES: Force Management - Economic Life Considerations, Volume IV

These reports have been entered into the DTIC/NTIS system. Contact the Avionics Integrity Program focal point ((513)255-3369) to obtain the appropriate report number for ordering.

The authors wish to acknowledge the cooperation and consideration afforded to them by Mr. Thomas Dickman, Mr. John Kaufhold, and Major Lee Cheshire of the Avionics Integrity Program Office during the conduct of these studies. Without their continuing guidance and interest, these reports could not have been developed. The authors would also like to thank Mr. Tom Dolash, Mr. Keith Broerman, Susan Hendershot, Nanci Peterson, and the Text Processing Center personnel at Battelle Columbus Laboratories for their contribution to these reports.

BACKGROUND

In time of war, reliable weapons systems ensure military readiness. The less support a weapons system requires, the more reliable the system is. For the military to effectively support a 30-day war requires that the avionics systems (LRU's) be ready and available to operate for 2,000 hours between removals (as stated by Major General Jasper Welch).

Avionics and electronics equipment are available today at the LRU level that can deliver 2,000 hours Mean Time Between Failures. This has been demonstrated and is achievable with technology that exists today with a minimal increase in acquisition cost. This is accomplished through the removal of defectives at the lowest level of assembly through effective Environmental Stress Screening (ESS). ESS is a concept; its effectiveness is achieved by exposing product to environments harsher than experienced in the field while not shortening its life. If the field use environment can cause the product to fail, then why can we not take this knowledge and move it into the manufacturing facility to cause these field-like environments to force-fail hardware in the factory? This ensures failure-free product in the field while testing the design forgiveness.

Effective March 1984, the proposal made by Senator Mark Andrews, Republican of North Dakota, will become law. His proposal requires all new weapons systems to be warranted to the Government, and it will become part of the DoD Appropriations Act of 1984, Section 794. This is a direct result of the demonstrations of poor reliability in military systems that are currently being seen. The 1984 DoD procurement budget is approximately $94.1 billion. Capser Weinberger stated that the current logistics support for the military is approaching 50 percent of the total military budget. Reviewing a portion of this budget for one of the military services disclosed an aircraft procurement appropriation where $1.966 billion is being expended, with logistics and modifications support totaling $828.7 million. Viewing this another way, 42.2 percent of the appropriated budget for this project is maintenance, modifications and spares provisioning.

The persons who are going to pay for this will be the taxpayers. DoD will be required to pay additional costs on top of their current costs to support this warranty system unless an alternate approach to reduce costs is obtained. A proposed method do achieve this reduction in costs is Environmental Stress Screening.

The methods of doing work today need to change, since the methods of yesterday have brought us to where we are. If defectives are removed from the field use environment and taken out of the product by the parts and systems manufacturers, the user will have failure-free product. To accomplish this, some of the funding that is currently in logistics support may have to be spent as part of the initial contract budget to cause these failures to be removed.

Currently, the life cycle cost of the manufactured product can be broken down into two basic cost sections, the engineering/production phase costs and the logistics support phase costs. This method of work which is being proposed SHOULD NOT COST MORE THAN 10 percent to 20 percent of the total acquisition cost. Assessing this cost against current contracts discloses the following: 10 percent of current life cycle logistics costs are equal to approximately 60 percent of acquisition cost. The savings to the Government by accepting a new method of work such as Environmental Stress Screening can be a logistics support budget reduction exceeding 30 percent of the current budget.

This approximately $25 billion savings (based on the 1984 Budget) can be had by the military if they ask for it. The decision now is DoD's. Change can give these savings. To accomplish this change requires that these questions be answered:

(1) How does a vendor propose a different approach than that specified by the current military specifications?

(2) How do you justify the high front-end development costs of integrity?

(3) How do you measure success or failure of a manufacturer and award the contract to a competent supplier who is not necessarily the lowest bidder?

(4) If the current method of work is not changed, then the message to industry is that DoD wishes lowest price and poor reliability. This results in marginal product and forces the manufacturers to supply poor quality and reliability with a get-well program financially based on the selling of spares provisioning. What is the message that should be conveyed?

EXECUTIVE SUMMARY

INTRODUCTION

A great deal of effort is being put forth today to improve product readiness. Many investigations are substantiating that improved reliability is necessary in fielded product. To cause this to occur, many people are turning to Stimulus Testing with varying degrees of success. Environmental Stress Screening (ESS) is a concept; its effectiveness depends on how well the concept is applied. This is an interim solution which yields results immediately and is cost-effective. The real problem is that in many areas of manufacturing, processes are not maintained to the degree needed for readiness. This may result in the design not being forgiving. The interim solution in this problem-solving role is to solve for immediate results while supporting the system.

PROBLEM

Product is failing in the field, resulting in loss of readiness. Assessed properly, one solution is to simulate and stimulate that field condition in the factory by developing accelerated tests to cause these failures to occur at the lowest level of assembly, which is most cost-effective. This will result in moving the field failures into the factory by force-failing latent defects, resulting in new fielded product which is as failure-free as possible. This will then meet the military challenge to industry as presented in Figure ES-1.

- Avionics must deliver 2000 hour MTBF.
- Defectives must be removed at the lowest part level.
- Built-in test should be less than 10% of electronic package.
- 10% logistic support can be a reality.

FIGURE ES-1. Military Challenge to Industry

Stimulus Testing is the exposing of product to environments which precipitate infant and latent defects at the lowest level of assembly while not degrading the product's life integrity. If this is accomplished for the worst-case field environment, then parts are more reliable in benign equipment uses. This is the key to Gould's formula for enhancing product quality as presented in Figure ES-2.

Mission Profile

- Identify worst case.
- Ensure integral parts can exceed it with margin.
- Develop ESS greater-than-mission profile where required to complement industry deficiencies to remove defectives.
- Failure-free performance in environment temperature cycling is a must.
- Assess field failures; determine if removal is possible at lower level.
- The Aircraft must not be the final production screen to remove defectives.

Designs

- Must be forgiving in all production systems in all environments.

Parts/Material

- Latent defects must be removed at the lowest level.
- ESS at levels greater than part design might be used.

Processes

- If it can't be controlled to the degree required, understand how it fails and test for it.

People

- All workers want to make good parts, but you must tell them what they are doing wrong - plot and chart problems and provide them with feed back.

FIGURE ES-2. Gould's Formula to Enhance Product Quality

Quality, produced by many companies today, is marginal at best as demonstrated by two basic observations:

- Poor field performance of military weapons systems is reported and compounded by high cost overruns.
- Logistics/spares provisioning costs are approaching if not exceeding 50 percent of the Defense Budget. (Logistics support should not exceed 10 percent.)

INVESTIGATION

Gould utilized field assessment and maintenance cycles in its study to determine why the MTBF in the laboratory was greater than the fielded MTBF by approximately four times. What was found was that the field requirements were more severe than the contract required. There was an incompatibility between the system reliability and the basic component requirements. There were few comments available meeting procurement specifications that were good enough to assure system performance in the aircraft exceeding 2,000 hours between removals.

This ESS program caused infant and latent defects to be removed earlier at the lowest level of assembly. This was accomplished by assessing what the actual aircraft use environments were; based on this, stress screens were developed whose exposures were far greater than the aircraft use environment. These stress environments often exceeded the military specifications by 10 times and far exceeded environmental exposures required at the component level.

FINDINGS

After five years of investigation and in excess of 1,200 equipments being manufactured of the same type, Gould has accomplished the following: the same product, which was designed in late 1960 with 4,000 systems processed in early 1970 having a laboratory demonstrated MTBF of 750 hours, had an additional 1,200 systems manufactured utilizing ESS at the lowest level of assembly, and has had this equipment achieve a laboratory MTBF exceeding 7,000 hours. Monitoring these 1,200 systems through the field discloses that this product demonstrates approximately a 2,000-hour MTBF in the aircraft.

One of the most important findings was that reliability is not consistently built into basic components, such as resistors, capacitors,

diodes, transistors, integrated circuits, etc., and the reason is that the average cost to manufacture is less than $1 per part. Since the average part manufacturer is a $50 million company, he builds more than $1 million worth of material per week. This means he has to produce in excess of $200,000's worth of material a day; if the part cost to manufacture is less than 10 cents, then he must produce in excess of 2 million parts a day, or approximately 250,000 parts an hour, or approximately 70 parts per second. With this kind of volume, it becomes of little concern to a parts manufacturer if his yield falls below 95 percent. This means that he could produce 100,000 latent defects per day, or approximately 500,000 per week. These can find their way into many avionics manufacturing facilities, causing product not to meet the desired reliability in the field.

CONCLUSION

Gould, Inc., Navcom Division, has found that: all of the knowledge of what is wrong with a product can be found in its defectives; assess and correct them, and you have a perfect product or system. This approach assures that reliability is built into all product by design.

If you assess electronic systems, you find: (a) that all electronic systems are the same. What makes them the same is that they are manufactured with the same families of components, (e.g., resistors, capacitors, diodes, transistors, integrated circuits, printed circuit boards, connectors, wiring, etc.); and (b) these part manufacturers are the same QPL sources who supply all electronics throughout the United States and the world.

With effective ESS applied to the above parts, existing failure mechanisms will be precipitated, and the result will be only the best parts being available for any electronic application. A failure is a failure in any piece of equipment and it will fail as a function of time and environment. If a methodology precipitates these failures at the earliest point in the manufacturing cycle, then you have the best product at the least cost in the shortest acquisition time with the highest reliability and lowest maintainability support. This is readiness, which is the goal that the Air Force is seeking in the current and next generation avionic systems.

1.0 INTRODUCTION

Building reliable product today can be achieved if the corporate commitment is made. This results in military support availability and readiness. This readiness is available today:

- in a shorter acquisition time
- at a lower life cycle cost
- with no impact on technology
- using Environmental Stress Screening (ESS).

This increased availability can be achieved at a minimal cost, however, it requires a formula for readiness which addresses the total military program field need and is carried out by the Avionics manufacturer. Gould's formula for readiness is presented in Figure III-1-1.

• IMPROVE MILITARY DESIGN	• BY USING PARTS THAT DON'T FAIL
• IMPROVE RELIABILITY & MAINTAINABILITY	• BY TRULY REMOVING INFANT & LATENT DEFECTS
• DIAGNOSTIC TECHNOLOGY	• WILL TELL YOU HOW TO CORRECT YOUR SYSTEM
• COSTS	• WILL BE LESS BECAUSE FAILURE WILL BE REMOVED AT THE EARLIEST POINT IN PRODUCTION
• CHANGES TO CURRENT SYSTEMS	• REQUIRES ASSESSMENT & PROPER ENVIRONMENTAL STRESS SCREENING (ESS)
• EQUIPMENT NEEDED	• STATISTICAL QUALITY CONTROL, DIAGNOSTIC TOOLS, AND ENVIRONMENTAL CHAMBERS
• IMPACT ON ACQUISITION	• LITTLE TO NONE

FIGURE III-1-1. Formula for Readiness

Field equipment must be inherently failure-free despite uncontrollable environmental conditions. The product being supplied should operate over its complete performance temperature range and be capable of completing its mission without any interrupts. When equipment fails to function, it is not fulfilling its mission intent. This section contains examples and data obtained by an organization (Gould Defense Systems, Inc.) that not only

complied to specifications but caused its equipment to exceed the contractual customer requirements through the use of Environmental Stress Screening methods, procedures and techniques. The resultant improvement is readiness. A review of Figure III-1-2 discloses the results obtained by Gould, Inc. on a system that initially had a contract requirement of 500 hours MTBF (with a predicted 1000 hours MTBF).

	MTBF	
ENVIRONMENT	WITHOUT ESS	WITH ESS
Lab	500 to 750 hours	1,000 to 7,000 hours
Field	50 to 200 hours	1,000 to 2,000 hours

FIGURE III-1-2. Result of ESS Tests at Gould

1.1 CONCEPT

Contracts which are released for new product require assessment of the design, the prototypes and the production hardware to meet customer requirements. The intent is to introduce sufficient planning into the program at its initiation to ensure that the end product will exceed the desired field use environment and performance. Utilizing a screening program to remove defectives at the earliest point in the production cycle has resulted in failure-free product at the lowest cost. The implementation of a screening program assesses hardware performance and compares it to the contractual requirements. This is accomplished by using stress screening at proper points in the production cycle to remove defects regardless of origin (e.g., design, part/material, processing, or workmanship).

Gould, Inc., has performed these assessments for a number of years on many products, which resulted in the development of new philosophies for readiness. These philosophies, when applied to new or old product designs, yielded the same results; improved product performance in the field. These Philosophies for Readiness are:

- All the knowledge of what is wrong with a product or company is in its defectives or problems; assess and correct and you will have perfected your company's systems and products.
- Nonreadiness occurs because integral parts fail even though the system concept is right.
- Conceptually, all electronics systems are the same; all designs use the same families of parts (e.g., resistors, capacitors, diodes, transistors, integrated circuits, complex hybrids, printed circuit boards, wiring, connectors, etc.) supplied from the same QPL sources.
- Systems do not fail; integral parts do.
- Systems only fail when the design is not forgiving.
- System/field reliability requirements are more severe than part qualification requirements.
- The quality organization today must be an assessment group which prioritizes anomalies and segregates them into their respective categories: PEOPLE, PROCESSES, PARTS/MATERIAL or DESIGN.
- Quality is an economical/financial/profitable state of mind that can be managed.

1.1.1 Design

Failures which are precipitated from fielded product must be understood and considered during the preliminary design of new product. Lessons learned must be applied causing parts or all of the system to be exposed to conditions which may exceed the specification limits to remove defectives at the lowest level of assembly. New designs should consider using stress environments above those specified in the Statement of Work or reference documents to test the design, parts, workmanship or processing utilized in the manufacture of the product. Stress environments will test the design concept giving the necessary assurance at the early stages that production equipment will meet the end mission requirements, resulting in readiness.

1.1.2 Design, Analysis, Development

A form of Environmental Stress Screening (ESS) which exceeds the design parametric goals needs to be used to test the design. If not used, then by what means will an initial design be tested to assure that all products produced through the manufacturing cycle and delivered into the field will meet their mission-intended goal? The military community is sending out a message that they want better product. (See Figure III-1.1.2-1.)

- Avionics must deliver 2000-hour MTBF
- Defectives must be removed at the lowest part level
- Built-in test should be less than 10% of electronic package
- 10% logistic support can be a reality

FIGURE III-1.1.2-1. Military Challenge to Industry

Product currently delivered to the military requires more logistics support than desired because fielded product is not reliable.

The designer must consider that each product being delivered will be utilized in environments that are harsh exposures, (e.g., thermal, vibration, dew point, barometric pressure, etc.) and can all occur simultaneously. (See Figure III-1.1.2-2(a)) The exposure might occur five to ten times in a single hour in the fighter aircraft and may see greater than 10,000 hours of operation during its normal useful life. Each flight is a minimum of one thermal cycle with all environments being exposed on the equipment simultaneously.

If accelerated tests are not utilized to demonstrate that equipment performance capability is obtainable, then what assurance will the designer give that will guarantee the producibility and mission performance of the end product? Figure III-1.1.2-2(b) shows that avionics manufacturers expose product to contract requirements which often are limited in frequency duration and are often one-time tests.

The designer needs to assess the cause of defectives under conditions that prevail in production and the failures that occur at the lowest level of assembly. The failure may be due to poor part quality or noncompatibility of a given part because the use environment may be more severe than the part's qualification requirements. (See Figure III-1.1.2-2(c)). Assessing these defectives and their causes can aid the designer in improving his producibility concept as well as his base design.

1.1.3 How A Quality System Can Support Production Resulting In Readiness

Product improvement is the result of a feedback system that assesses the performance of previous designs as well as failures of product to meet the initial design intent. The organization that can support this information-gathering is the Quality operation. Its chartered responsibility is to act as the auditor of product performance on behalf of a customer. If a quality product is to be manufactured, then an entire quality system, assessing all segments of the operation, from design to field performance, needs to exist. This complete umbrella of assessments determines where non-performance characteristics exist, and where corrective action needs to be taken.

All of the knowledge of what is wrong with a product or a company is in its defectives or problems. Assess the defectives or problems, determine the source of the problem, take the necessary corrective action, and you eliminate the condition. This results in product improvement.

When a company incorporates a Quality By Assessment program, it must utilize Statistical Quality Control. This method of work utilizes Pareto-type charting to develop histograms. They pinpoint the total number of defectives at major points in the design or production cycle and tabulate them in percent defective against the total number of items being manufactured. This allows a company to self-assess and determine where the problems are. Detailed investigations into problem areas result in additional Pareto charts breaking product down into the source of the problem. Correcting these problems results in product improvement, which is equipment readiness enhancement.

1.1.3.1 MIL-Q-9858 Is A Must

MIL-Q-9858 requires that a company have a quality system which is an assessment program of each of its segments. A quality system must assess the four major segments of: design, procurement, manufacturing and standards. Assessing each of these segments through the use of Statistical Quality Control can result in determining where problems occur and what action is necessary to correct them.

(a) Fielded Product Assessment

Aircraft	Needs
• 20-Year Life	• Average Fighter Aircraft
• 20,000 Flight-hour life	• Can be greater

• >20,000 environmental cycles	• Thermal > -50°C to +[illegible]°C
	  • Can be 1°C to 100°C A per minute
	  • Each flight is a thermal cycle or more
	  • All parts must survive cycling or shock

	• Dewpoint/moisture absorption

	• Vibration
	  • Sine 5 to 2000+ H_z 10g's plus
	  • Random 5 to 2000+ H_z 10g's plus
	  • Conducted acoustical
	  • Gunfire

	• Shock Impact > 100 g's plus
• 10 Hours between repairs	• EMI/RFI: No loss with each repair/removal
	• Bit test lowers product performance
	• Logistics support greater than original costs

CONCLUSION: RELIABLE PRODUCT IS RARE

(b) Avionics Manufacturer's Assessment

The contract is law.

Test (100%) to pass and ship (make a profit).

Combined Environmental Reliability Test (CERT) 100%

• Thermal System	o -54°C to +71°C o rate of change air 5°C/Min o Power: Off in cold, on in heat
• Vibration System	o 2 g's fixed frequency
• Humidity System	o 80% at dew point

Failure Assessment Limited

Production Reliability Testing Periodic

• Salt	• Limited
• Rain	• Limited
• EMI/RFI	• Limited
• Shock	• Limited
• Immersion	• Limited
• Life Demo	• Limited
• Vibration	• Limited
• Other Test	• Limited
In Process Testing	• Limited
Receiving Inspection Tests	• *Limited* (80% of all electronic parts in a system cost less than $1)

(c) Parts Assessment

QPL

- The manufacturer had a process once that allowed him to make and assemble a lot which passed qualification.
- During QPL Test, failed parts can be substituted.
- Substituted parts can result in latent lot process failures.
- Some QPL products can have 10% latent defects by design.
- Unique environments are qualified with <20 parts.
  - High-low temperature exposure 5 cycles. A rate of change 5°C per minute.
  - Vibration = 10 to 2000 H_z (potted in wax)
  - Burn-in steady state high temperature.

PRODUCTION PARTS

- Allowable failure rate is a function of yield.
- MIL-STD-105D 1.0 AQL single normal (1 to 5% defective is normal).
- Many parts see no environmental exposure until system or aircraft use.

CONCLUSION: Part lots contain infant and latent defects.

FIGURE III-1.1.2-2 a,b,c. Observations Based on Fielded Product, Avionics Manufacturer and Parts Assessments

1.1.3.2 How To Make It Work

Any company that desires to manufacture a reliable product can do so by merely assessing the performance of its products in the field. If a company corrects the deficiencies that exist in the user's environment and makes its product failure-free, it has manufactured a quality product. Establishing a data collection system that reports deficiencies at any point in the production cycle will result in problem awareness followed by problem solving. By breaking all problems down into four basic groups (design, parts/material, people, and processing), an assessment organization can easily determine into what category the problem should be placed, thereby allowing it to be assessed and eliminated.

1.1.3.3 Workmanship And Design Standards

Minimum established standards are normally the result of a problem or noncomformance condition which resulted in product failures. If manufactured product met all the needs of a customer and performed satisfactorily in the use environment, then standards could be realistically changed.

1.1.3.4 Understanding Reliability

Product that delivers in excess of 2,000 hours of operation without an interruption or failure is classed as a reliable product. All conditions that reduce the overall mission performance of the product must be investigated. Those conditions that deter from the mission must be corrected to enhance the reliability. There is no such thing as a nonrelevant failure in the field since any failure that occurs impairs mission performance. These conditions must be assessed and the origin of the problem eliminated at any point in the product life cycle, thereby enhancing the product reliability - which is readiness.

1.2 A SYSTEM TO PRODUCE RELIABILITY

Assessing the contract and its Statement of Work against the equipment's intended use environment may require that the contractor consider the implementation of ESS which will force failures at the lowest level of assembly. This gives credibility to the design and it assures that it will result in product readiness. To accomplish this requires assessing the use environments of the product. Gaining knowledge on similar fielded product and incorporating methods of work to "guardband" the design assures a forgiving design. Many of the referenced specifications in the contract and Statement of Work are guideline documents to which product is to be manufactured in order to yield a workable product or system. The specification intent is to result in reliable product, but this is not occurring in the field. IT IS THESE SPECIFICATIONS WHICH HAVE PUT CURRENT PRODUCT INTO A STATE OF LOW READINESS. Reliability today is achieved through spares provisioning and not built-in quality. Consideration needs to be given to these specifications, since many of them contain minimum test requirements which may not precipitate infant and latent defects. It is the responsibility of the contractor to devise methods of work to precipitate infant and latent defects at the lowest level, which is most cost effective. It should not be the aircraft which precipitates defectives thereby reducing the mission readiness of the aircraft and increasing life cycle cost.

How do you deliver reliable product when the sub parts have not been designed for the mission requirement? A comparison between aircraft manufacturer and parts can be seen in Figure III-1.2-1. How can the end product be reliable when the field requirements are more severe than parts were designed to meet?

1.2.1 Understanding The Mission Requirements

If a company wishes to deliver reliable product which meets the mission profile intent, then it must understand the true life cycle performance of the product. A method of work which will yield a reliable product is one which reviews the worst case condition for the use and always designs for it. If integral parts are screened for the worst case environment, which precipitates established failure mechanisms, then any system into which they are put will yield high reliability in a more benign environment.

In the case of fighter aircraft, its normal life cycle can be twenty years. During that time, it is expected that the aircraft will operate an average of less than one hour per flight. Therefore a system overall life performance will require that the product be capable of being turned on and off while being subjected to its full environmental extremes. The product should be capable of surviving in excess of 20,000 of these cycles. This is the intended use of avionics in a fighter aircraft. If the design and the integral parts used have the capability of meeting this, then the overall performance of the product will yield the reliability desired.

Condition	Aircraft	Avionics Manufacturer	Parts
Life	20,000 Flight Hours 10,000 Standby Hours 30,000 Hours Plus	15,000 Hours Projected, or Demonstrated, or by Similarity	20,000 Hours Plus
	All Environments Combined 100% All Product	Sample Test Accelerated	Sample Test Accelerated
	20-Year Life	Design Modeling	Sample Test Accelerated
Thermal High-Low Exposure	>20,000 Cycles	25 Cycles	*0 to 30 Cycles
Thermal Rate	Up to 100°C/Minute	5°C/Minute	5°C/Minute
Dew Point/ Moisture Resistance	>20,000 Cycles	*Sample	*Sample
Vibration			
Sine	>20,000 Hours	*Sample, 12 Hours	*Sample, 12 Hours
Random	>20,000 Hours	*'0' or Sample	None
Acoustical	>20,000 Hours	None	None
Gunfire	Periodic	*One Time	None
Shock Impact	>20,000 cycles	*Qualification	*Qualification
EMI/RFI	100%	*Sample	*Sample
Altitude/Barometer	Each Flight	*Qualification	*Qualification

*Possible one-time test.

FIGURE III-1.2-1. Comparisons

The problem with most systems can be seen in Figure III-1.2.1-1 which shows the aircraft is the final environmental chamber.

WHAT'S WRONG?

- Few companies look at the system failures from the field.
- Failures must be removed in the factory.
- Infant and latent defects must be removed at the lowest level of assembly.
- If the process can't be maintained cost effectively to the degree required, then an alternative approach must evolve (Environmental Stress Screening).
- Product performance doesn't exceed field needs.
- Many companies test to pass:
  - Allowing defectives to precipitate to the field,
  - Defects are too expensive to remove,
  - Failures are non-relevant,
  - All product is not tested to worst-case condition,
  - High failure rate in the company prevents thorough investigations.
- Is 100% receiving electrical testing effective? No
- There is a negative incentive to make reliable product:
  - You must bid too low to win a program,
  - Losses are overcome by selling marginal product at a low cost and spares at a high cost.

FIGURE III-1.2.1-1. The Aircraft is the Final Environmental Chamber and the Worst Case

Avionics manufacturers and piece part manufacturers never subject their product to meeting the requirements of a worst case environment. Do suppliers subject their product to 10,000 plus hours of operation in the combined environment simultaneously? In the case of a fighter aircraft, each system must be capable of surviving this. If product is to be maintained as failure free as possible, then the methodology employed must be capable of achieving this desired goal.

1.2.2 What Is The Desired Failure-Free Performance?

Product can be manufactured today at a reasonable added cost (approximately 10 percent of each contract) that can deliver readiness. Avionics equipment can be manufactured consistently to deliver without interruption 2,000 hours of operation. The only time the system should be non-operating would be for a planned maintenance where state-of-the-art components may not be capable of achieving this failure-free period then maintenance cycles are instituted.

1.2.3 Can The Product Be Made To The Contract Demands?

Avionics product can be manufactured today to exceed 2,000 hours Mean Time Between Failures (MTBF) without interrupt if a plan to accomplish the same is supported by management. To achieve an MTBF of this order requires a management commitment. This commits a company to a total system, thereby continually improving designs as well as the manufacturing process.

This requires a corporation to establish a methodology that causes defectives to be precipitated at the lowest level and the knowledge gained fed back to the appropriate department to cause correction of deficiencies, resulting in improved readiness. This results in low manufacturing cost, high quality and product readiness. This work method was employed on the ARN-84, see Figure III-1.2.3-1, where reliability improved and the life cycle cost wa

	QUANTITY PER SET	TOTAL SETS PROCESSED	TOTAL PARTS USED	TOTAL REPLACED	REPAIR COSTS	REPAIR COST PER SET	MAXIMUM ALLOWABLE COST ADDED PER PART TO REMOVE DEFECTIVE
CAPS	1,017	1,203	1,223,451	127	$12,700	$10.56	$.010
CONNECTORS	340	1,203	409,020	46	4,600	3.82	.011
RESISTORS	1,714	1,203	2,061,942	104	10,400	8.65	.005
DIODES	368	1,203	442,807	68	6,800	5.49	.014
TRANSISTORS	396	1,203	476,794	264	26,400	21.95	.055
ICS	530	1,203	637,590	177	17,700	14.71	.027
	4,366	1,203	5,254,704	784	$78,600	$65.17	$.122

*$100 AVERAGE COST TO MAKE A REPAIR

AVERAGE COST TO REPAIR AND MTBF

QUANTITY	AVERAGE COST TO REPAIR	MTBF
173	$186.60	725
240	148.74	803
667	80.70	887
660	80.87	1088
143	78.09	—
291 (STIMULUS SETS ONLY)		2425
1188 " " "	66.80	3300
1203 " " "	65.18	3342

FIGURE III-1.2.3-1. AN/ARN-84 Failed Parts Cost Analysis

reduced. As the quantity of products increased, the average cost to repair was reduced, since defectives were removed at the lowest level of assembly. This has resulted in fewer failures seen at the system level, with minimum failures seen in the field. This product was subjected to ESS at varying levels. The previous 4,000 systems processed without ESS only achieved 750 hours MTBF at best. By instituting ESS, the overall cost to manufacture was reduced, as can be seen in Figure III-1.2.3-1, where the cost to repair was reduced while the MTBF was increased. The result is better product delivered.

By using ESS as a process tool, the near-term improvement can be achieved today in new as well as established systems. This method of work allows parts and systems to achieve the best reliability at the lowest cost.

1.2.4 Are Parts Good Enough?

Extensive studies have been made attempting to determine if electronic components are good enough "off-the-shelf" to deliver reliability. The conclusion of many companies is that parts require additional screening above QPL levels if they are to survive and deliver the reliability levels commensurate with a 2,000 hours MTBF system. In a study performed by the Institute of Environmental Sciences in 1980[1], it was found that of some 35 major aerospace manufacturers, military installations as well as commercial houses, all performed some degree of added testing via their receiving inspection.

Resistors, capacitors, diodes, transistors, and integrated circuits were assessed and had greater than 1 percent defectives detected as a minimum with as high as 5.3 percent defectives found in some families. This study included levels of commercial, higher than commercial, QPL, and higher than QPL component families. In almost every case, each company that responded to the questionnaire exposed the product to additional stress screening.

To achieve a 2,000-hour MTBF system, the part quality level must be better than .999 failure free. Part failures can have an avalanching effect at the system level if quality is not maintained as is shown in Figure III-1.2.4-1. QPL means that a manufacturer had the ability and formulation at one time to manufacture parts that were in full compliance with the qualification specification. During qualification testing, failures are allowed to occur and, if the number of defectives is within the acceptable range, then no corrective action may be necessary. This can result in latent defects by design. Performing qualification testing to gain a QPL listing sometimes allows the test lot to contain additional substitute parts that can be used in the event of failure. This can lead toward part families having infant or latent defects within the product by design.

Sampling plans allow 1 percent or more defectives in any lot established. MIL-STD-105D, 1.0 AQL, single normal allows 1 percent to 5 percent defectives in a lot. Can a manufacturing facility produce a quality system with an incoming quality level exceeding 1 percent infant and latent defects? (See Figure III-1.2.4-1) If a lot of 600,000 parts had 1 percent

- Requirement = 2,000-Hour MTBF System.
- System = 3,000 Electronic Parts.
- Production/Month = 3,000 Parts x 200 Systems = 600,000 Parts/Month.
- Burn-In (MIL-STD-810C) = 600,000 x 50 Hours = 30,000,000 Parts Hours
  = 30 Meg x 4.2 (Accelerated Aging Factor)*
  = 126,000,000 Parts Hours/Month.
- High Reliability Parts = 1 Defective per 50,000 Burn-In Hours.
- Failed System Parts = $\frac{126,000,000}{50,000}$ = 2,520 Failed Parts/Month.
- Failed Parts/System = $\frac{2,520}{200}$ = 12.6 Failures per System/Month.
- A company cannot be properly managed when 2520 parts fail per month, causing each system to fail 12.6 times prior to shipment. This results in high field failures.

CONCLUSION: THIS MEANS PARTS ARE NOT GOOD ENOUGH

* See MIL-HDBK 217.

FIGURE III-1.2.4-1. Are Parts Good Enough

defectives you would expect over 6,000 defectives. This order of magnitude of defectives would create havoc in a company if a system is not in place which is capable of assessing and reducing defectives.

If the defectives are collected, plotted, charted, and analyzed for cause of failure, then corrective action can be taken. If additional information is gathered, an assessment can be made to determine if the components are being stressed only in one specific location or if it is common throughout the system. This would be the first trend that determines whether the part might be defective or if the design is nonforgiving.

By having a system in place that collects defectives and categorizes them by part name, number, and system location, a company can assess whether there is a problem with a component, the design, or if damage is being incurred during the manufacturing. When it is determined that components are not good enough, then additional exposures and/or testing may be required to precipitate infant and latent defect removal at the lowest level of assembly.

Examination of component reliability requirements versus system end use environment discloses that field requirements may be more severe today

than when the specifications were originally written. Aircraft perform one thermal cycle or more during each flight. Changes in altitude or speed also result in additional heating or cooling cycles. Components' real field life environment means that, each day or flight, components are exposed to every environment which is tested during qualification environmental exposure. Assessments need to be made if the numbers of exposures that are required during qualification are less harsh during component design and test phase or if the aircraft use environment is harsher. The majority of QPL specifications reveal that the aircraft use environment is harsher than the qualification requirements and/or the sustaining requirement for QPL listing. Therefore, it is expected that components will fail at a very high rate in aircraft use.

What is needed is a method of work where infant and latent defects are precipitated when exposed to ESS that are based on the harshest use environment which does not detract from the life of the component or the mission requirements of the end item.

1.2.5 Fab-To-Print/Spares Provisioning

In procurement of spares provisioning, improved reliability can be had at little cost above orginal contract cost by using the methods employed herein. Environmental stress screening can be implemented on old and new designs where parts can have their failures precipitated at the lowest level of assembly with MTBF improvement on fielded product.

1.2.6 Vendor Control

To assure that good material is received, it is necessary to monitor vendors' performance, not only in receiving inspection but under a variety of factory conditions. At any point during the production cycle that anomalies are noted, they are retested to verify procurement as well as system requirements. When deficiencies are noted, this information is fed back to the source of supply to obtain corrective action. Material received which meets the design intent but fails to function in the system is coordinated between engineering, procurement, and the vendor to establish the correct limits for future procurements.

1.2.7 Part Qualification

Selected parts which meet QPL or have gained military nomenclature are not always useable as-is for military needs. Military branding means only that the source of supply has had the formulation to manufacture it at one time. This does not mean that all of the parts are of consistently sufficient quality and reliability to perform to the ultimate goals of both the product manufacturer and the end user. It is these parts, today, that are yielding the current field MTBF which requires high logistic support. The avionics industry utilizing QPL electronics or hardware often must perform additional tests above and beyond specification requirements. This substantiates that parts today are not good enough. An avionics supplier must assess the failures that are precipitated from production and the field. Collecting

parts and assessing where and how they failed, along with the performance of diagnostic analysis, can establish the condition that caused the failure to be precipitated. This can aid in the establishment of special tests (ESS) which will precipitate infant and latent defects. Establishing an environment above and beyond the requirement of the procurement document creates the criteria for parts ESS development. If parts are to survive in the use environment, they should be capable of taking exposures above and beyond established limits. Therefore, by utilizing ESS on new product received, an organization can assess vendor parts for reliability integrity.

1.2.8 The Need For Diagnostic Analysis

Diagnostic analysis is a methodology that assesses the manufacturing process integrity of an item regardless of its complexity. Diagnostic analysis is the method which disassembles the failed part and establishes the primary cause of failure. Properly performed, it can establish the primary failure mechanism, and determine if it can be prevented or if a screen must be developed for further detection. Diagnostic analysis assesses the complete manufacturing process, weighs this against the use environment and determines if the part is proper for its intended use. It assesses if the part was improperly manufactured or if the failure can be attributed to the loss of process control during its manufacturing cycle (see Figure III-1.2.8-1). Diagnostic analysis also aids in determining if the use environment is harsher than the base design environment. When this occurs, then the only parts that may be available would be those parts that are screened. Establishing how parts fail under what sets of circumstances allows for the avionics manufacturer to determine if it has the best part for a given application. It is often cost advantageous to use an environmental stress screen to precipitate infant and latent defects than to try to maintain the control of a manufacturing process.

1.2.8.1 All Systems Are The Same

Electronics systems are all basically the same, whether they be DC power supplies used in test equipment or flight computer hardware. This is because they are manufactured using similar types of components, such as resistors, capacitors, diodes, transformers, transistors, integrated circuits, PC boards, cables and harnessing, etc., supplied by QPL suppliers. What makes these systems different are the power levels, the frequencies at which they are operated and their packaging density. Electronic systems are manufactured with the same families of components supplied by the same sources of supply. Precipitate infant and latent defects for a worst case environment and these same components will work in a lesser environment.

1.2.8.2 Process Control Versus Yield

Electronic components that comprise approximately 80 percent of the average avionics package normally cost less than $1. Component part manufacturers are in business to make a profit, the most economical

FIELD EVALUATION

- Pathological studies of failures,
- What environments precipitate what failures,
- Develop screen to precipitate failures,
- Develop screen that may be 100 times greater than aircraft - system - part requirements,
- Self-imposed screens at the lowest level system - module - part.

SYSTEM EVALUATION

- Test to precipitate failures in the factory,
- Assess defectives at all levels,
- Each unique screen precipitates different failures,
- In-house screens must be more severe than those in the field.

PART EVALUATION

- All active and passive devices require added screening.

FIGURE III-1.2.8-1. What Gould Has Done

process often is to manufacture great quantities, then grade. (See Figure III-1.2.8.2-1.) This means that a part manufacturer may have to produce in

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ELECTRONIC PARTS MANUFACTURERS

- Manufacture in bulk and grade,
- Material cost <$.10 ,
- Labor cost <$.10 ,
- Process cost <$.10 ,
- Sell price <$1.00 (yield 50%) .

$50-MILLION MANUFACTURERS - CAN THEY MAKE RELIABLE PRODUCT?

- Must ship $1 million a week ,
- Must ship $200,000 a day,
- Must make 500,000 parts per day ,
- Must make 62,000 parts per hour,
- Must make 1,042 parts per minute ,
- Must make 17 parts per second .

CAN PROCESS CONTROL BE MINTAINED TO SUPPORT THE AIRCRAFT?

CONCLUSION: NO

FIGURE III-1.2.8.2-1. Parts Manufacturers' Assessment

excess of one million parts per day in order to yield a day's shipment. If a million parts are produced a day, then greater than 2,000 parts are manufactured per minute. If there is a loss in process control during this period, it is difficult to ascertain where in the cycle it went wrong and which parts are suspect. The parts manufacturer must determine where the economical yield point is and how much process control can be exercised at what cost. It could be economical if the yield is only 10 percent and he throws away 90 percent. Semiconductors at the wafer level often yield less than 80 percent, and in the case of very complex integrated circuits or LSI, a process yield may be only 10 percent. The evident defectives are removed from the assembled lot, the questionable ones are allowed to continue, and then are removed at subsequent levels of screening or testing. This can introduce questionable material which passes all part testing yet may contain a number of infant and latent defects which will be precipitated in the use environment.

1.2.8.3 How Do Parts Fail?

Electrical failures can be classified into three basic categories: mechanical, DC, or AC failures. When this concept of electronic part failures is carried one step further, it can be said that there is no such thing as an electrical failure, since all characteristics which are measured electrically have failed mechanically first.

When it is understood how parts fail, a methodology can be utilized through the concept of stress testing to cause the parts to fail early in the production cycle and at the most economical point. There exist failures from opens to shorts with varying degrees of performance in between for all classes of manufactured parts. The detection of existing conditions needs to occur by force failing parts at the most cost-effective point in the production cycle.

1.2.8.4 Acceleration of Defectives

Knowing how parts fail and under what set of circumstances allows a method of work to be developed. This ESS method may exceed the basic design of the item or component; however, it precipitates infant and latent defects. Properly developed, these exposures do not degrade the overall mission performance of the end product. This is derived through a total system of assessments ranging from the parts manufacturer's facility through avionics integration, and the field.

Systems comprise 10,000 active and passive devices which are capable of surviving hundreds of thermal cycles while less than .5 percent fail in the system in the field. It is these critical defectives which must be isolated in the factory. This percentage of defectives must be removed from the field by the avionics manufacturer and ultimately the component manufacturer at the lowest level of assembly.

1.2.9 Worst Case Environments

The term "worst case environment" means different things to different segments of industry. The three basic areas that establish a worst case condition are: field, the avionics manufacturer's facility, and the piece part manufacturer's facility.

There are some five basic groupings for electronics: test equipment, undersea, ground support, space, and flight hardware. Each of these areas determines what exposure the hardware will be seeing; therefore, each group may assess his worst case condition differently. (See Figure III-1.2.9-1.) There is a commonality in each of these areas, parts which go into the electronics are the same, as previously described. All electronics are manufactured using the same families of components from the same QPL suppliers. Knowing the worst case environment and having a single methodology to screen out infant and latent defectives is cost effective.

1.2.9.1 The Fighter Aircraft Profile

The worst case field environment (of the five) is the fighter aircraft. The fighter will see harsh environments more rapidly and more frequently than any other use environment. Avionics is simultaneously exposed to temperature, humidity, vibration, EMI, acoustical noise, shock, and many others with each flight. (See Figure III-1.2.9.1-1.) These fatiguing environments occur each time aircraft speed or altitude is changed. The

MISSION PROFILE

- Identify worst case .
- Ensure integral parts can exceed it with margin.
- Develop ESS greater-than-mission profile where required to complement industry deficiencies to remove defectives.
- Substantiate that all production equipment meets critical design performance characteristics.
- Failure-free performance in environment temperature cycling is a must .
- Assess field failures; determine if removal is possible at lower level.
- The field must not be the final production screen to remove defectives.

DESIGNS

- Must be forgiving in all production systems in all environments.

PARTS/MATERIAL

- Latent defects must be removed at the lowest level.
- ESS at levels greater than part design might be used.

PROCESSESS

- If it can't be controlled to the degree required, understand how it fails and test for it.

PEOPLE

- All workers want to make good parts, but you must tell them what they are doing wrong - plot and chart problems and feed back.

FIGURE III-1.2.9-1. Gould's Formula to Enhance Product Quality

aircraft may perform greater than 20,000 thermal cycles during its life. Is there an avionics manufacturer or component manufacturer who has tested to this level?

WORK METHODOLOGY

- Must precipitate failures

RANDOM VIBRATION (WORKMANSHIP SCREEN)

- 10 minute period
- 6G RMS

THERMAL SHOCK

- Component cycling 5 to 10 times MIL SPEC
- Module lowest level of assembly 15 to 25 cycles plus
- System cycling requires 5 failure free cycles minimum.

FIGURE III-1.2.9.1-1. Gould's Implementation of ESS

The aircraft is the final environmental chamber and is the worst case condition since it accumulates the harshest environment more rapidly than any other exposure. If the ESS methodology will precipitate defectives that would normally occur in the aircraft worst case environment, then it should be capable of being used for all equipment applications, old or new. This methodology can be implemented in any factory, at the lowest level of assembly and inexpensively compared to other normal life cycle costs.

1.2.9.2 Parts Versus Aircraft Profile

Aircraft profiles require that all piece parts be capable of meeting mission performance to the degree required by the intended field use. This is the basis for the philosophy for readiness. (See Figure III-1.2.9.2-1.) In every case, whether it be test equipment, ground support, flight, or space hardware, the piece parts must survive the environments to which they are being exposed. Field use requires 100 percent performance.

1.2.9.3 How To Develop Part Screens

Assessing what fails in a life cycle can establish which screens need to be developed to precipitate a given failure mechanism. (See Figure III-1.2.9.3-1.) The three main failure review areas are field, in-house, and

PARTS

- QPL only means the supplier had the formula once; it doesn't guarantee consistency.
- Process control can't be maintained for desired military need.
- ESS for known failure mechanisms.

SYSTEMS

- Don't fail, parts fail.
- All use parts from the same suppliers.
- Only fail when the design is not forgiving.
- Need ESS for known failure mechanisms.

RELIABILITY

- System requirements are more stringent than component requirements.
- ESS for known failure mechanisms.

ANALYZE DEFECTIVES

- All of the knowledge of what is wrong with a system is in its defectives.
- Correct for defectives and you evolve a perfect system.
- Ensure corrective action through feedback systems.
- Devise ESS for failure mechanisms.

ASSESS ALL STEPS

- PEOPLE, PROCESSES, PARTS/MATERIAL, DESIGN.

QUALITY IS A STATE OF MIND THAT CAN BE MANAGED

FIGURE 1.2.9.2-1. Readiness Philosophy

part. Failure diagnostics establishes the failure mechanism and the point where the failure occurred, which, in turn, will indicate the number of environmental exposures required to precipitate it. By assessing where the failure occurred and what precipitated it, the engineer can devise a method of work to precipitate that family of defectives.

RANDOM VIBRATION

- Detects poor design and workmanship.
- Corrective actions will solve defects.
- Test all production units or sample test to keep check and balance, as required.

THERMAL SHOCK

- Conduct at lowest levels of assembly.
- Failures occur early, find at low level assembly test.
- Removes 99% field failures at manufacturer's facility.

FIGURE III-1.2.9.3-1. Gould's Rationale for ESS Test Elements

Utilizing a stress screen at the appropriate point in the manufacturing cycle may be the most immediate and most cost-effective approach to implementing readiness.

1.3 WHY FAILURE ANALYSIS WORKS

Diagnostic analysis is an effective tool in determining the primary cause of failure. Whether product is defective in the field, factory or at the component manufacturer's facility, the proper assessment can determine where a failure occurs.

All the knowledge of what is wrong with a product or a manufacturing facility can be found in the defectives or the problems that exist. Assess defectives or problems and correct for the primary cause of failures, take positive corrective action to eliminate the basic cause, and the problem is solved. Diagnostic analysis, and the breakdown of a problem into its proper category, allows for the engineering and management talent to be applied to that area which will yield product improvement by correcting the primary cause of the failure.

1.3.1 Failure Assessments

The mere collection of failures throughout a product's production and life cycle is not sufficient to cause corrective action to occurs on its own. Assessment needs to be made at each point where failure occurs in the product's life cycle to assure that the true probable cause of failure is found. (See Figure III-1.3.1-1.) It is this collection of information, along with the diagnostic analysis, that allows the total system to be assessed. Failures occur and are stimulated in many ways. This requires a review by an assessment group with an analytical approach to determine the order of magnitude and establish the primary cause of failure along with the environment that caused the precipitation. This alone does not solve the problem of how to eliminate the primary cause of the failure. Further investigation and information feedback to the appropriate organization must be initiated and followed up.

1.3.2 People/Processes/Parts/Design (Feedback - What Has Been Done)

What has been done? When assessments are made yielding the primary cause of failure, then the appropriate area in which the failure occurred must be assessed. Breaking problem areas down into one of the four basic constituents of people, processes, parts, and design allows that group to do an assessment and devote their energy to those activities that allow them to correct the identified condition(s).

Collecting defectives and disseminating the information allows for the contribution of all parties in a constructive manner, to cause problem solving to occur which results in the elimination of the problem.

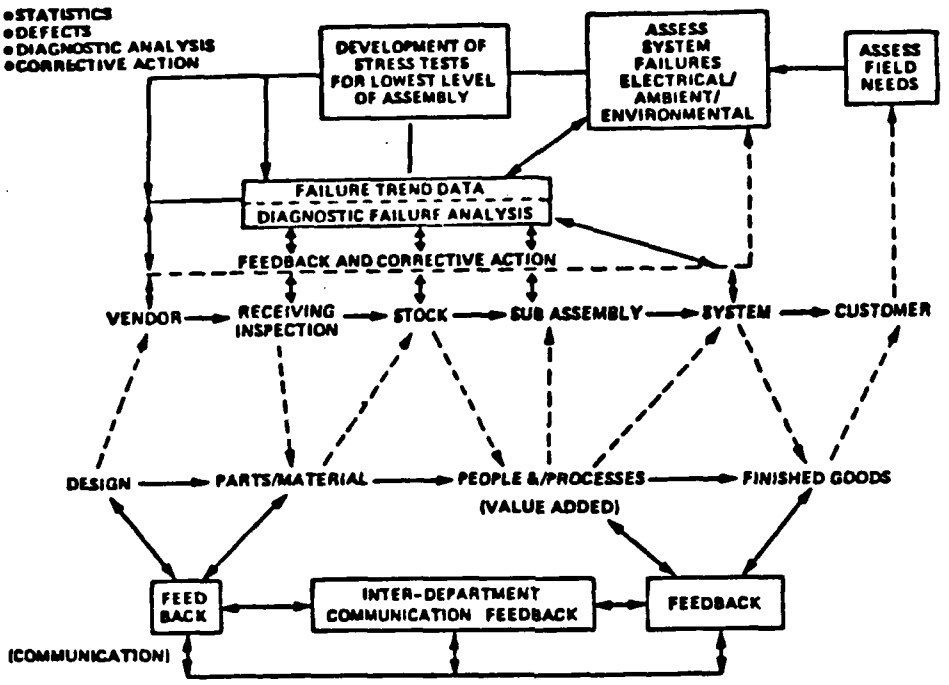

FIGURE III-1.3.1-1. Failure Assessment System

1.3.3 People and Tools Needed and Their Associated Costs

To perform the needed work functions requires a combination of talent and tools. (See Figure III-1.3.3-1.) An assessing organization requires diagnosticians along with production tools to stimulate defectives. Each area will have its own unique tools and allocated costs. (See Figure III-1.3.3-2.) ESS is the basis for diagnostic analysis of failed parts. The primary cause of failure must be established (on parts that have been precipitated during ESS) which in turn assures that the established ESS is doing its job. Data collection on failed parts allows a statistical analysis to be performed and emphasis can then be placed on those areas which give the greatest return for the investment. ESS is applied at the appropriate lowest level of assembly in the form of vibration or thermal stress. Figure III-1.3.3-2 shows the related equipment needed and the associated cost for equipment and functions.

1.3.4 Failure Analysis

Performance of failure analysis has many meanings to many people. There are those who presume they are performing failure analysis when they take a component, test it to the procurement specification, and determine if it is good or bad. This is only the first step of failure analysis. If the

- Environmental chambers-temperature.
- Environmental temperature shock.
- Vibration equipment-random.
- Computerized environmental control.
- Pathological tools:
  - X-Ray,
  - Microscopes to 400 mag plus,
  - Scanning electron microscope to 50K mag plus.
  - Physical parts analysis (incoming inspection).
- Electronic pathologists.
- Parts/vendor control.
- ESS as a process control:
  - Vendor,
  - Receiving,
  - System,
  - Field.

FIGURE III-1.3.3-1. ESS Tools

< $1.00 PER HOUR = COST TO OBTAIN A 2,000HR MTBF

	VENDOR	RECEIVING INSP.	SUB ASSEMBLY	SYSTEM	
THERMAL 6000 PARTS/SYS	10C/PART $600/SYS	DPA@$ 5.00/LOT 5 X $ 5.00 = $ 25.00/SYS	ESS $ 20.00/SYS	$ 240.00/SYS	$ 785.00/SYS
VIBRATION				$100.00/SYS	$ 100.00/SYS
THERMAL CHAMBERS *(INCL. VIB) VIBRATION			CHAMBERS $ 70K $ 250K	CHAMBERS 120K = 190K ÷ 2000 SYS = 250K ÷ 2000 SYS =	$ 95.00/SYS $ 125.00/SYS
				APPROXIMATE COST PER SYS TO OBTAIN A 2000 HR MTBF	$ 1105.00

FIGURE III-1.3.3-2. ESS Cost to Obtain a 2000 Hour MTBF

part meets the procurement specification but fails at a higher level of assembly, this is the first indication that a design deficiency might exist under various sets of circumstances. Additional investigation would be required to determine why a part which meets the procurement specification does not work in its next higher assembly or does not work in a specific environment.

If the device under test fails to meet the procurement requirement, then Destructive Physical Analysis (DPA) needs to be performed to determine why the device does not function. This would mean that the device would have to be tested to determine that it was out of specific test parametric limits. This would be followed by a destructive analysis to the level to determine the primary cause of failure. In the case of semiconductors, it would mean removing the case while not disturbing that portion of the basic component for its active elements. This would be followed by an investigative optical analysis to determine what caused the device not to function. If the device disclosed an open or short condition, this would be investigated by optical analysis at magnifications up to or exceeding 400 power. In the event that higher magnification would be required, it may require Scanning Electron Microscope examination utilizing magnifications greater than 10,000 times. These examinations far exceed the requirements of the basic specifications, but they are a necessary part of the investigative process to properly determine the primary cause of failure within the device.

Other analysis might be required, such as lead bond pull or die shear. Both of these tests would be to determine the mechanical integrity. Investigations into material purity through X-ray analysis would determine if contaminants are on the face of the die. This contamination may be precipitated by a hermetic seal leak in the case introducing contaminants on the active area of the device. Additional investigations might be to cross-section the die if an anomaly is noted that might appear to be a sublayer fault. This may indicate that contamination was present when an oxide layer was formed, causing the device to fail prematurely.

This type of failure analysis requires an in-depth knowledge of the manufacturing process for a given device; this is the task of an electronic pathologist. With knowledge of how the device failed, the diagnostician can determine the source of the problem. The diagnostician can make a determination as to the severity of the problem, what corrective action should be taken, and the cause of the problem: random occurrence, a technician error, abuse in handling, static discharge destroying the device, the design was not forgiving, the device failed due to a thermal runaway, etc. There can be any number of reasons why the device failed. It is the diagnostician's responsibility at the time of failure analysis to establish the primary cause and determine what corrective action needs to be taken and if parts need to be purged at varying levels of the production cycle. If it is a latent defect, then the diagnostician may determine, based on his historical records and the pattern problems noted, that all devices be subjected to a form of stimulus testing to force fail any devices which may exhibit a similar pattern of failure.

1.3.5 Cost of Analysis

One of the first examinations that is normally performed on any defective device is an optical assessment. Simple inspection using a high-powered, single-lens, 2 to 10 power, magnifying glass costs anywhere from $1 to $100 dollars.

Simple microscopes with low-power magnification are available for under $200 giving magnifications from 2 to 30 power. Metallurgical-microscopes with binocular eye pieces, 10 to 400 power, are available at costs up to several thousands of dollars. These have varying attachments such as light field and dark field illumination as well as a camera for picture-taking capability. Dependent upon the microscope desired, and the accessories required (wider fields of view with greater focal depth working distances), the prices range from $1000 to $15,000.

Greater magnifications with greater depth of field can be had through the use of a Scanning Electron Microscope (SEM). There are many types of SEM's on the market ranging from $10,000 to in excess of a quarter of a million dollars. The difference is the size of the specimens that can be viewed and the type of information yielded. SEM's that have limited specimen size as well as magnifications are on the lower end of the price scale, whereas expensive units have very high magnifications and offer extra capabilities such as X-ray analysis of primary elements.

There are independent sources of supply who perform diagnostic analysis using optical as well as SEM capabilities. These services can be bought on an hourly or daily rate for the performance of investigation. These companies will supply reports which range from basic testing through visual and DPA analysis to optical photographs, SEM photographs, and X-ray element analysis of the device under investigation. The costs from outside sources range from $50 an hour up through several hundred dollars per hour.

Having trained personnel in the plant requires sustaining a work force which includes as a minimum a BSEE, a Manufacturing Engineer, a Parts Engineer, and possibly other skills dedicated to this task. Unfortunately, due to the high cost, electronic pathologists of this type are not usually found in a manufacturing facility.

1.3.5.1 Electronic Tests and Costs

Performance of electrical tests on components can range from a simple resistance test to a complex setup for integrated circuits through hybrids. Dependent upon the degree of test to be performed, it can range from a simple setup to complete automation for production hardware. When performing tests on less than a dozen parts at a single time, simple electrical setups are normally made to test the base devices at a minimum lot charge of $25 or per part cost ranging from $.10 to $10.

1.3.5.2 Mechanical Analysis Tools

Depotting equipment might be needed if the product is constructed of a plastic base. This requires sufficient chemicals to dissolve the plastic, which costs less than $50 per gallon.

When dies or other electronic components are of miniature size and might have an internal short in the base structure of the device, that device may have to be cast into plastic. Once the device is cast into plastic it can be ground, polished, and the surfaces lapped in order to look at a cross section of the device. Polishing and lapping material can be obtained for less than $500 to perform an adequate analysis of parts.

Semiconductors could require other tools, such as fine and gross leak testing for hermeticity. This type of equipment can be bought for approximately $10,000. This testing can also be performed by an independent laboratory for a lot charge of less than $100. Semiconductor lead bond pulls can be done with a simple force gauge costing approximately $15. More expensive equipment can be obtained for less than $1,000 which is semi-automatic and can record the actual gram force of the lead wires in a nondestructive or destructive nature, depending upon the setup of the device. Die shear can be performed by using simple force gauges, costing less than $100.

These tests can be performed within a company or they can be performed by outside laboratories which are equipped to perform this type of work on a regular basis, at reasonable costs and quick turnaround.

1.3.5.3 Environmental Equipment and Its Costs

In the process of removing defectives at the lowest level of assembly, various ESS exposures can be required. The environments which cause field failures to be precipitated need to be examined. The fighter aircraft can see ram air temperature changes of 100 degrees C per minute. If the aircraft were to go from sea level to 40,000 feet in less than one minute, the product in the air flow with ram air cooling could be exposed to a rate of change of 100 degrees C. Even if the aircraft did a thermal rate of change or climb to altitude in 4 minutes or less, the thermal rate of change would be approximately 25 degrees C per minute. The aircraft and its equipment are subjected to four types of vibration: sine, random, conducted acoustical, and gunfire. Avionics can see these vibrations simultaneously.

During a single flight the aircraft and its equipment will see simultaneously: high and low temperature, vibration, altitude/barometric pressure differentials, salt atmosphere, dew point and moisture. When changing altitudes, the aircraft goes through dew point combined with the barometric pressure, allowing component parts to see cold temperature breathing which can result in moisture penetration if a hermetic seal is not maintained. Excessive numbers of these cycles can have a deteriorating effect on hybrids and/or semiconductors. The environments that would be needed to precipitate defectives during the manufacturing cycle must be considered for all of these environments at their appropriate point. This may

require that an analytical assessment of the total operating system be in place. (See Figure III-1.3.5.3-1.)

DEFECT ANALYSIS AND CORRECTIVE ACTIONS ELIMINATE FUTURE FAILURES

FOR EACH PROBLEM AREA, "TEST" OR ASSESS

To determine area of origin:
- DESIGN
- PARTS/MATERIAL
- PEOPLE
- PROCESS

Frequency of occurrence (order of magnitude).

Prevailing environment when occurrence was noted.

Establish failure mechanisms.

Devise ESS to precipitate failures at lowest level.

Purge system of suspect parts, implement ESS, take corrective action.

MONITOR SUCCESS AND FINE TUNE RESULT

FIGURE III-1.3.5.3-1. Analytical Quality Assessment

A diagnostician must have test equipment available to simulate the field environment in which the failure has occurred. The equipment necessary should be similar to that which is used to precipitate the defectives during normal production. This equipment must have the ability to exceed the avionics use environment, if it is to precipitate defectives at an early point in the manufacturing cycle. Diagnostic analysis also aids in determining if life is being removed from the product.

Types of equipment needed are high and low pressure chambers, vibration equipment, altitude, salt and moisture chambers, as well as EMI capabilities. Other capabilities, such as solderability, fine leak and gross leak equipment, centrifuge, may be needed. These tests may be performed by outside laboratories.

Chambers performing thermal exposures range from $15,000 up to approximately $100,000 dependent upon physical size and refrigeration and heating packages required.

As can be seen in Figure III-1.3.5.3-2, costs of subjecting product to environmental exposure fall into two categories: the recurring cost of

performing the function, and the nonrecurring one-time cost related to the procurement of equipment. In the event that testing at the vendor's facility is to take place, then these recurring costs would still continue and the nonrecurring cost would not be applicable.

PARTS	Recurring System Cost	Nonrecurring One-Time Cost
• VENDOR		
• ESS more than QPL requires	$500.00	
• All major part families		
• RECEIVING ACTIVITIES	25.00	
• Analysis of failure history		
• Destructive parts analysis (DPA)		$10K
• Lot data code logging/tracking		
• Scanning Electron Microscope Analysis		30K = 100K
• INPROCESS		
• ESS lowest level of assembly	20.00	
• Failure analysis feedback to ESS temp chamber		70K
• SYSTEM		
• ESS high/low temp	240.00	
• Temp chamber		120K
• Vibration random	100.00	
• Vibration equipment		250K
	$885.00	$\frac{\$550K}{2K\ sys.} = 275.00$
	$885.00 + $275.00 = $1,160.00	

FIGURE III-1.3.5.3-2. Cost of ESS

The three basic implementation areas of ESS are: receiving/ inspection, in-process, and the highest level of assembly or system. In each, failures can be precipitated; therefore, diagnostic analysis to simulate the condition would be directly related to the area from which the failure occurred. Chambers should be selected for the worst case condition. The rates of change that would be required for diagnostic analysis should be a direct result of a stimulation test to precipitate a defective rather than a simulation test for that which the product should be capable of meeting on a daily and routine basis. Simulation tests can result in latent defects by design. Performing qualification testing to gain a QPL listing sometimes

allows the test lot to contain additional substitute parts that can be used in the event of failure. This also can lead to part families having infant or latent defects within the product by design.*

If the defectives are collected, plotted, charted, and analyzed for cause of failure, then corrective action can be taken. If additional information is gathered, an assessment can be made to determine if the components are being stressed only in one specific location or if it is common throughout the system. This would be the first trend that determines whether the part might be defective or if the design is nonforgiving.

By having a system in place that collects defectives and categorizes them by part name, number, and system location, a company can assess whether there is a problem with a component, the design, or if damage is being incurred during the manufacturing. When it is determined that components are not good enough, then additional exposures and/or testing may be required to precipitate infant and latent defect removal at the lowest level of assembly.

Examination of component reliability requirements versus system end use environment discloses that field requirements may be more severe today than when the specifications were originally written. Aircraft perform one thermal cycle or more during each flight. Changes in altitude or speed also result in additional heating or cooling cycles. Components' real field life environment means that, each day or flight, components are exposed to every environment which is tested during qualification environmental exposure. Assessments need to be made if the numbers of exposures that are required during qualification are less harsh during the component design and test phase or if the aircraft use environment is harsher. The majority of QPL specifications reveal that the aircraft use environment is harsher than the qualification requirements and/or the sustaining requirement for QPL listing. Therefore, it is expected that components will fail at a very high rate in aircraft use.

When all functions of ESS are totaled throughout the manufactured process, the overall implementation cost will range from 10% to 20% above the basic contract cost. This cost could be reduced further if a company demonstrates that it is building quality in its product; then expensive environmental testing at the system level might be eliminated. Additional savings might also be seen now that the methods of documentation, process control, inspection, etc., might be reduced. This means that the contract

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* Sampling plans allow 1 percent or more defectives in any lot established. MIL-STD-105D, 1.0 AQL, single normal allows 1 to 5 percent defectives in a lot. Can a manufacturing facility produce a quality system with an incoming quality level exceeding 1 percent infant and latent defects? (See Figure III-1.2.4-1.) If a lot of 600,000 parts had 1 percent defectives you would expect over 6,000 defectives. This order of magnitude of defectives would create havoc in a company if a system is not in place which is capable of assessing and reducing defectives.

cost might be the lowest cost when innovation is allowed to reign over the current methods of contracting. The end results would be a lower equipment cost with a life cycle cost reduced by greater than 50% of current work methods.

1.3.6 Data Collection - How It Works For You

By collecting data related to failures a comparison can be made to determine the similarity between failures which occur; and how defectives at higher levels may be force-failed at lower levels of assembly. Introducing ESS at the lowest level is cost effective. (See Figure III-1.3.6-1.) As can be seen in the figure, the cost to remove defectives at the lowest level reduced the cost of production by 50 percent. This is an actual study on in-house cost reductions. If total cost savings were to be considered for the full life cycle cost, then the savings would be greater.

Failure Removal	Pre Stimulus Testing			Post Stimulus Testing		
Location	Parts	Systems	Cost	Parts	Systems	Cost
Vendor or Screening House	None	N/A	N/A	Lot Related 25 to 10% (Ave. 5%)	(20,000) *	$24,030/100 Systems
Receiving Inspection (Vendor Chargeable)	2.5%	(10,000) *	Normal	Vendor Chargeable .2%	(800) *	Reduced
In-Process 1st Test Post Stimulus	5000 Defects / 400,000 (1.25%)	(5,000) *	$25,000	500 Defects / 400,000 (.075%)	(500) *	$ 2,500
Burn-In	500 defects / 400,000 (.125%)	5 failures/ system (500) *	Cost to Repair $100,000	180 def. / 400,000 (.045%)	1.8 failures/ system (180) *	$36,000
Burn-In/AET	12 defects / 400,000 (.003%)	1.2 failures/ 10 systems (12) *	$2,400	2 defects / 400,000 (.0005%)	2 failures/ 100 systems (2) *	$ 400
TOTALS:	5,512 defects	(15,512)*	$127,400	682	(21,482)*	$ 62,930
CUSTOMER REACTIONS	QUESTIONING PERFORMANCE			HIGH DEGREE OF ACCEPTANCE		

FIGURE III-1.3.6-1. Stimulus Testing Results

1.3.6.1 Failures and Segregation

Failures needs to be broken down into the respective families as well as areas from which they came. Parts that fail should first be divided

up and plotted using Pareto-type analysis to establish commonalities of failures that are occurring within given families. By looking at what parts fail from what vendors, a determination can be made if a given fault exists within a given family of parts in a given application. The second method of plotting data, assesses the failure for a location on the board to determine if a deficiency exists for a given part only in a specific location. By plotting and charting in this manner, a diagnostician is able to assess where the potential problem might be, and what might have precipitated it.

The plotting and charting should be done across each of the specific work function areas. This allows the statistician and diagnostician to look at the implementation and cost effectiveness of ESS. (See Figure III-1.3.5.3-2.) Cost related to implementation can be evaluated in terms of reliability and accuracy of judgment. Continued fine-tuning of the method of work can determine how much further the diagnostician needs to cause change to occur. The intent of failure analysis is to determine where the problem is, under what sets of circumstances it was precipitated, and where the corrective action needs to take place.

III-1.3.6.2 Failure-Free Performance

If a diagnostician has performed his work properly, he should have instituted a methodology which precipitated defectives at the lowest level of assembly. (See Figure III-1.3.6.2-1.) If product being delivered to the customers is to be failure-free, it should be demonstrated in the factory.

The number of exposure cycles should exceed the number of cycles which precipitated the greatest number of defectives from the product.

When QPL parts were placed into a fighter aircraft-type environment, it was found that failures were still precipitated for the next 20 or more thermal cycles of normal field use. (See Figure III-1.3.6.2-2.) The total number of exposures to precipitate defectives could exceed 50 before field deployment in order to insure that all infant and latent defects were identified and removed.

Failure-free environmental cycles, with stabilization at each extreme, must be performed to substantiate that the total number of defectives had been precipitated during previous exposures at the equipment level. Companies have processed several hundred pieces of equipment through the failure-free cycle to substantiate that 24 thermal hours is a minimum time period necessary to assure that infant and latent defects had been identified and removed.

1.3.7 Systems Performance - High and Low Temperature

Qualification systems assembled by engineering, who understand prevailing conditions, usually pass qualification testing, while fielded product often has high failure rates.

LABOR	• Rework labor is eliminated
	• Production delays are eliminated
	• Scrap is eliminated
	• Retest cases are eliminated
	• Lost time is eliminated
MATERIAL	• Scrap allowance is reduced
	• Material cost is reduced
	• Reprocurement is eliminated
	• Parts acquisition time is reduced
CONCLUSIONS	• Building it right the first time lowers cost
	• Less acquisition time
	• Fewer field failures
	• Readiness improvement
	• Customer satisfaction

FIGURE III-1.3.6.2-1. Building Quality in is Cost-Effective to Manufacturer, Government, and Taxpayer

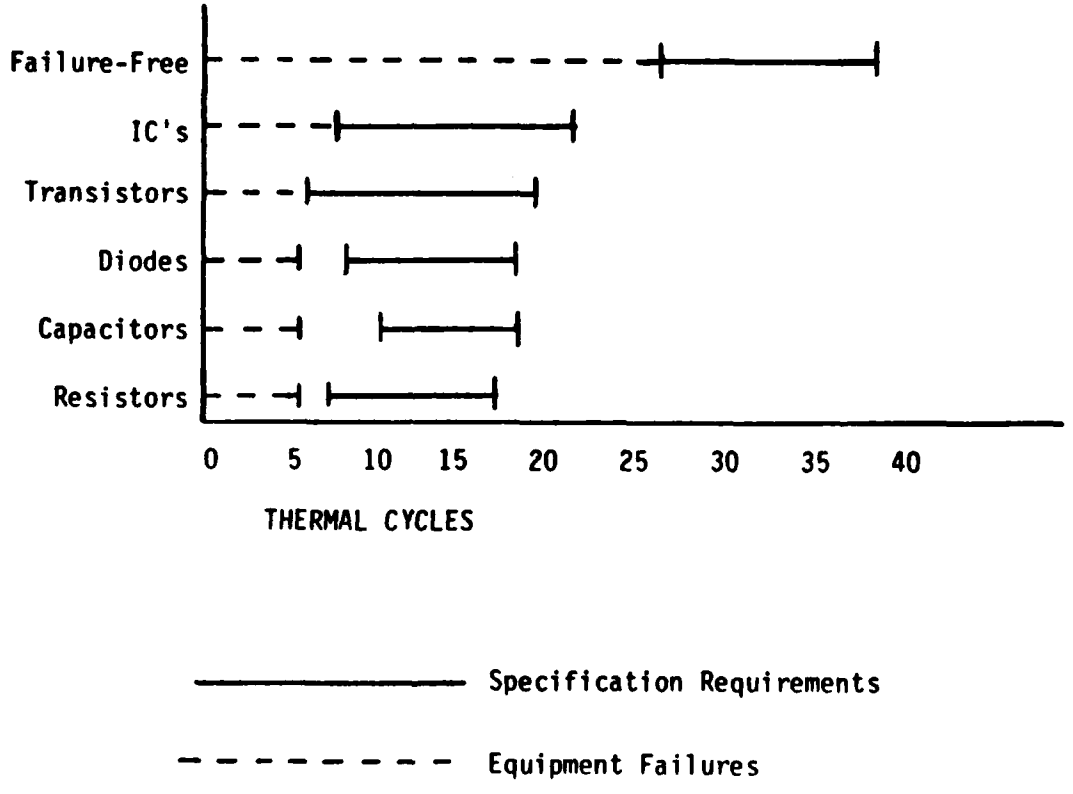

FIGURE III-1.3.6.2-2. Lack of Thermal Cycling at the Component Level

All fielded systems must be capable of performing 100 percent over any combination of environments at any time which might be equal to or greater than qualification requirements. If product is to survive field use it should be capable of surviving all environments simultaneously. To guarantee these requirements requires that all product be subjected to high/low temperature extremes while still in the factory. This will give the assurance that product being delivered will have a confidence of surviving. To manufacture product as failure-free as possible requires product be subjected to a field-like environment or worse while still at the factory.

1.3.7.1 Combined Environmental Reliability Testing (CERT)

MIL-STD-781 and MIL-STD-810C are simulation specifications to demonstrate that product has the ability to meet design criteria. It is not the intent of CERT to precipitate failures; therefore, through the utilization of failure diagnostics and a feedback system, a form of ESS can be devised to remove defectives at the lowest level of assembly. After this kind of a system is put in place, then CERT will substantiate that product has the ability to meet the field use environment. When this type of system is put into use, then you can expect to see the results as reported in Figure III-1.3.7.1-1.

System	Quantity of Systems Assessed	Active & Passive Electronic Parts	Defective	Laboratory Failure Fee Hours	Field MTBF
ARN-84	1,203 (Parts/Sys.) (4388)	5,254,704	12 1 400K	5,000	2,000
URN-25	73 (3000)	291,927	2 1 148K	3,100	Sea 35,000 Land 50,000
CV-3510(-1)	142 (1012)	143,704	2 1 70K	TOTAL HRS. 3950 2,414	100,000
TRN-30 VI	47 (585)	26,555	4 1 6.6K	3,600	NO DATA RECEIVED
V2	16 (585)	9,040	2 1 4.5K	1,100	

FIGURE III-1.3.7.1-1. Systems MTBF

1.3.7.2 How Much? How Long?

To determine how much CERT should be in place should be a direct function of field product performance. When field data substantiates that the contracted reliability is being met, then we have established that the proper amount of CERT is in place. A feedback system tells if failures are being precipitated into the field. Field assessments determine if the reliability is or is not being met. An assessment for defectives can determine what needs to change.

When a complete system is in place, then the number of hours of CERT can be reduced as long as the field demonstrated reliability is being met. CERT testing should not be eliminated.

1.4 CONCLUSIONS AND RECOMMENDATIONS

1.4.1. Conclusions

To achieve a reliable system in the field requires that a complete assessment operation exists which covers process monitoring from design to field use. By assessing the total system, one can determine where the problems are and how they can truly be solved. This can be summed up in five basic philosophies:

A. All knowledge of what is wrong with a product can be found in the defectives. Assess your defectives and they will tell you how to correct your product or how to improve your system.

B. All electronic systems are the same, since they are manufactured using the same basic components procured from the same sources of supply.

C. Systems don't fail, integral parts or components with the systems fail; a system only fails when the design is not forgiving.

D. There is no such thing as an electrical failure, since all electronic failures when equated to their primary failure mechanism are either mechanical, chemical, or physical in nature.

E. If the field use environment can precipitate defectives by assessing how, when, and where they occur, a diagnostic group can establish the methodology which is called Environmental Stress Screening, to remove the defectives at the lowest level of assembly.

Environmental Stress Screening is a concept; how it is applied will determine its effectiveness. Many people assess Environmental Stress Screening as they perceive it. However, if they do not raise the level of reliability of product in the field to the level required by the customer, then this method of ESS is ineffective.

If the current method of work, which created the current situation which we are in, is continued to be used, product costs would stay the same and logistics support will continue to grow. This is a ten year historical pattern in DoD, where current logistics suport cost is approaching or exceeding product mission cost. In some instances, problem product logistics cost is approaching 10 times the original construct cost.

If ESS is utilized to compliment the current system, the current cost will be increased by approximately 10-20% dependent upon the expertise of the manufacturer. On the other hand, if a corporation were to utilize ESS, as it should be utilized --utilizing the best workmanship and the best parts and complimenting the design through an assessment system, the overall cost of the product can be reduced. Manufacturing product properly the first time results in the best parts at the lowest cost, with the highest reliability in the shortest acquisition time--which is readiness.

Many of the things that we are doing today are "crutching" the system and do not enhance product performance and furthermore, can be eliminated. It is the elimination of the unnecessary specifications, and the extensive tests that are simulations, which do not enhance cost performance, as well as redundancies in paper work, which do not yield higher reliability. The elimination of these areas will cause the initial system cost to be reduced, and readiness can be had at a lower cost than is currently contracted for--still resulting in logistic cost reduction.

The bottom line is that if the unnecessary paperwork and regulations are eliminated, and the manufacturer is allowed to use the best parts and processes the product can be made right the first time; with a resultant reduction in initial product cost and reduced logistic support and cost. Today's estimated 10-20% cost increase due to the application of ESS must be looked at in concert with the current methodologies of work and regulations, which gives the overall appearance of a cost increase. However, in view of reduced logistics support costs that will result, the overall life cycle cost is reduced by greater than the initial 10-20% added cost.

If the system is changed, eliminating unneccessary tests and paperwork, then the initial product cost will also be reduced while still reducing logistics support costs.

For example, if instead of using military QPL parts, the use of industrial level parts (whose proven reliability exceeds QPL) can cause a parts cost reduction of greater than 50%. If PCB soldering techniques utilizing "active" flux were used, then the controls and "cost adders" required to minimize lead and part oxidations are eliminated (through the use of active flux), resulting in an estimated overall cost reduction of at least 200% with estimated improved product reliability of 400%.

1.4.2. Recommendations

The effectiveness of ESS is only as good as the knowledge disseminated in this new field of product exposure. What is needed is the upgrading of personnel in many areas through a tutorial tailored toward each segment of industry, e.g., detailed and written for personnel in Contracts, Procurement, Quality, Engineering, Program Management, etc. Each of the tutorials and the plan for teaching the same should be adapted for each group. All of the components expounded upon should also be part of a program plan for new contracts. This will require an audit program establishing if a company has knowledge pertaining to ESS and if there is sufficient staff or capability to perform the necessary work functions.

A common reporting system should be established which can be used by DoD contract managers to assess all companies equally. The reports should be contractually required to disclose to the Program Office the effectiveness of the ESS within the manufacturing facility as well as assessing field performance of delivered product.

The effectiveness of any program is only as good as the knowledge of the individuals attempting to put this methodology into practice. A lesson plan and an instructional procedure with checklists are necessary to further this program and to cause change in industry which will result in readiness for the services.

1.5 REFERENCES

1. Environmental Stress Screening Guidelines, ESSEH, Sponsored by the Institute of Environmental Sciences, 1981

(Additional material related to parts, per se, is available from J. Capitino, Gould, Inc.)

*U.S.Government Printing Office: 1984 — 759-061/161

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